Audit and remediation of fish passage barriers in coastal NSW

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Abstract

Within Australia, riverine connectivity has been disrupted through the installation of numerous instream fish passage barriers in the form of weirs, dams, road crossings, and floodgates. These barriers impact native fish populations by interrupting spawning and seasonal migrations, restricting access to essential habitat and food resources, and altering habitat condition and water quality. As a result, the NSW Department of Primary Industries initiated an extensive audit of instream structures (weirs, dams, road crossings, and floodgates) for the purpose of detailing the location and extent of fish passage obstructions across the NSW coastal catchments. In total, over 3300 barriers were identified and subsequently prioritised regarding their impact on migrating fish. Road crossings accounted for over half of all barriers identified, with pipe culverts and causeways accounting for the majority of impediments for this structure type. Floodgates accounted for an additional third of all barriers, with hinge-flapped gates being the predominate design. Although weirs accounted for < 15 % of identified barriers, the majority of such structures were located on priority waterways resulting in high remediation rankings. Remediation considerations including design options (e.g. fishway installation, auto-tidal floodgates) and overall project costs are described for each barrier type.

Keywords

Fish passage, migration, weirs, dams, road crossings, floodgates

Introduction

Within lotic systems, Australian native fish have evolved to be reliant on a variety of habitat types to complete their life cycle, thereby requiring free movement within rivers and streams and between estuarine and freshwater environments. Of the 55 freshwater species found in New South Wales, 32 are considered ‘migratory’ as defined by the movement of a large proportion of a population between two or more distinct habitats with a regular pattern (Thorncraft & Harris, 2000; Northcote, 1978). However, all species display the propensity to move between varying aquatic environments. While fish migrations are commonly associated with breeding events, additional motivations for species to disperse include the search for food and shelter, and the avoidance of predation and competition pressures. Unfortunately, riverine connectivity has been severely disrupted within Australia by the proliferation of instream barriers to migratory fish that limit habitat and resource availability and threaten the fitness of species to adapt to changing environmental conditions (Pethebridge *et al.*, 1998; Gehrke *et al.*, 2002).

Australian fish are generally poor swimmers and jumpers, especially when compared to their northern hemisphere counterparts (Mallen-Cooper, 1992). As a result, structures such as weirs, dams, road crossings, and floodgates can act as physical barriers due to excessive headloss (i.e. the ‘waterfall effect’) or hydrological barriers due to high water velocities and turbulence. Impacts associated with fish passage barriers include restricted access to preferred habitats and resources, restricted breeding opportunities, and in extreme cases localised extinctions (Thorncraft & Harris, 2000, Gehrke *et al*,. 2002).

Although current policy within NSW legislates for the incorporation of fish passage into the design of all new waterway crossings, a legacy of poorly designed structures exists that detrimentally affects native fish. As a result, the NSW Department of Primary Industries (NSW DPI) initiated an extensive audit of fish passage barriers across the State’s coastal catchments that encompassed weirs, dams, road crossings, and floodgates. Once identified, barriers were prioritised to guide management decisions pertaining to the rehabilitation of fish passage. The final aim of the project was to establish rehabilitation projects across the spectrum of fish passage barrier types to demonstrate best practice techniques in barrier remediation.

Fish barrier audit and prioritisation

Extensive field surveys were conducted of all coastal catchments in NSW to determine the location of fish passage barriers. The audit focussed upon waterway crossings on 3rd order systems and above, with offstream structures (e.g. farm dams) and waterway crossings on 1st and 2nd order streams generally being overlooked except for floodgates. Topographic maps (1:25000), GIS drainage and road network data layers, and State and local government registries were utilised to highlight potential barriers that required inspection.

Initial site assessments were completed using paper datasheets; however, this approach was subsequently changed to a GIS based digital assessment proforma in order to improve the accuracy, efficiency, and consistency of data collection. A fish passage barrier program (FishBarriers V.1.2) was developed in ArcPad (V.6.03) and uploaded onto a handheld PDA which provided a field-based spatial record of all barriers and non-barriers assessed. Data initially recorded in the field included GPS location, structural description (e.g. weir/dam), habitat and watercourse details, location identifiers, and barrier type (e.g. excessive water velocity). Following the field-base audit, a detailed desktop investigation was conducted on identified barriers to determine ownership details, relative position to other fish passage obstructions, and additional environmental considerations (e.g. presence of threatened species).

A waterway barrier prioritisation scheme was developed to assist in ranking identified obstructions to fish passage. Barriers were prioritised based upon their catchment location (tidal versus headwaters), habitat class (Fairfull & Witheridge, 2003), relative position to other obstructions (e.g. available upstream habitat), barrier type, aquatic and riparian habitat condition, and structural condition (e.g. obsolete or damaged). Barriers located within the lower reaches of a catchment in a permanently flowing, major waterway were given higher weighting than fish passage impediments found in the upper catchment in systems that displayed minimal fish habitat (e.g. ephemeral flowing gullies). Additionally, the number of downstream and upstream obstructions and the available habitat above a barrier influenced the structure's ranking, with the lowest barrier in the catchment generally receiving the highest priority score. The resulting ranks provided an initial shortlist of high priority barriers to further investigate within each catchment. Additional factors that were not included in the initial prioritisation but required further consideration included social attitudes, economic costs, and political ramifications of proposed works.

Fish barrier audit results

A total of 3317 barriers to migrating fish were recorded during the NSW coastal fish barrier audit, with road crossing barriers generally being the most prolific barrier type encountered. Road crossings accounted for over half (1743) of obstructions recorded, while floodgates accounted for a third (1117) of fish passage impediments. Weirs and dams were the least common barrier encountered (13.8 %; 457).

Table 1. Summary of road crossing structures and associated fish passage barrier types recorded in NSW coastal catchments.

	Structure Type						
	Pipe Culvert	**Box Culvert**	**Causeway**	**Ford**	**Bridge**	**Other**	**Total***
Total	**664**	**313**	**610**	**120**	**20**	**26**	**1743**
Headloss	336	164	440	55	11	15	1021 (58.6)
Velocity	332	46	133	6	1	1	519 (29.8)
Flow Depth	325	182	309	77	12	5	910 (52.2)
Debris	130	40	101	16	7	3	297 (17.0)
Slope	26	10	26	9	1	2	74 (4.2)
Other	28	12	0	0	0	0	40 (2.3)

* numbers in parenthesis indicate percentage of total road crossing obstructions that displayed that barrier type

The primary fish passage barrier types observed at road crossings were excessive headloss (58.6 %) and shallow flow depth (52.2 %), followed by high flow velocities (29.8 %) and debris accumulation (17.0 %; Table 1). The type of barrier observed at a crossing was dictated by the design of the structure, with multiple barrier types possible at a single barrier. Generally, bridges promoted the natural, unimpeded flow of water beneath the structure's deck which allowed for the free movement of fish over a wide range of hydrological conditions. However, bridges built too low, or whose piers and footings constricted the channel, detrimentally affected hydrological flows and subsequently fish passage. Along coastal NSW, bridges accounted for only 1.1 % (20) of road crossing impediments (Table 1). Alternatively, pipe and box culverts accounted for 38.1 % (664) and 18.0 % (313) of road crossing barriers respectively. Culverts are designed to convey flow beneath the roadway; however, if the cross sectional area of the culverts constrains water flow, or the invert of the culverts is set above bed level, fish passage can be compromised. The primary fish passage barriers observed at piped crossings were excessive headloss and water velocity, and insufficient flow depths (< 100 mm) through the culverts (Table 1). Unlike pipe crossings, high water velocities are often not observed at box culverts. Instead, excessive headloss and shallow flow depths associated with perched box culverts are the primary barriers typified by this design (Table 1). Low level crossings such as causeways are generally constructed at or near bed-level and are designed to convey water across the road surface as sheet flow. Although causeways tend to drownout quickly, fish passage is often obstructed during low flow periods due to excessive headloss and shallow flow depth across the structure (Table 1). In some cases, causeways may also incorporate low-flow pipes beneath the roadway that can further restrict fish passage as outlined above for culverts. Finally, fords are formed to the contour of channel beds as wet crossings, which generally eliminates the waterfall effect unless downstream bed lowering has occurred. Fish passage barriers associated with fords are commonly attributed to shallow flow depths during low-flow periods.

Weir and dam barriers recorded in the fish barrier audit were primarily fixed crest concrete structures of small to medium height (1 – 3 m) located in the middle to upper reaches of the NSW coastal catchments. The primary function of weirs is to impound water for town water supply, irrigation, industrial use, power generation, and stock and domestic requirements. As a result, the chief fish passage barrier type recorded at weirs and dams is excessive headloss or slope (> 95 %), depending upon whether the structure has a stepped or angled downstream spillway. Few regulating structures were recorded during the survey (< 5 %), with drop boards being the primary means to alter water discharge rates or weir pool height.

Floodgates were originally designed as hinged flaps that aimed to limit floodwater pooling on low-lying agricultural land. The hinged flap gate was the predominant design recorded during the audit, accounting for 78.1 % (872) of floodgate barriers. More recently, winch gates have been inserted onto drains, thus giving landholders and floodplain managers the ability to actively regulate the amount and duration of tidal exchange. However, due to the regular maintenance associated with the control of the winches, gates can be left closed for prolonged periods during which fish passage is obstructed. Approximately 19 % (212) of floodgate barriers recorded during the fish passage audit were winch gates. Sluice gates are standard hinge gates that incorporate a sliding panel fitted over a custom-made hole that allows the regulation of tidal exchange. As with winch gates, active management is required for sluice gates to permit tidal flushing and fish passage. Less than 1 % (10) of floodgate barriers were attributed to sluice gates, primarily due to the low number of such gates in operation. Autotidal gates overcome the regular maintenance issues of winch and sluice gates by using tidal levels to control a float-based trap door system. Although self cleaning, inspections are required to ensure that the gate is operating properly. No fish passage barriers were recorded for autotidal gates during the audit.

Fish barrier priority results

Despite being the most prolific barrier type recorded, only 10.3 % (180) of road crossings were determined to be high priority fish passage impediments compared to approximately a quarter of all weirs (27.6 %; 126) and floodgates (25.5 %; 285). The low number of priority road crossing barriers is attributed to the catchment location and surrounding habitat quality of identified structures. Greater than 50 % of road crossing impediments were located in the upper catchment, with only 14.7 % situated in the lower reaches. Additionally, 50.6 % (883) of road crossings barriers were located on Class 3 or 4 systems that display minimal fish habitat (Fairfull & Witheridge, 2003), with only 7.2 % (125) of waterway crossings located on major permanently flowing rivers (Class 1). Although a similar catchment distribution was observed for weirs as for road crossing barriers, the majority (> 70 %) of water impoundments were located on Class 1 and 2 streams (i.e. named permanently flowing creeks and rivers with known fish habitat; Fairfull and Witheridge, 2003), thereby resulting in a higher priority ranking. Given the nature of floodgates, all structures of this barrier type were located in the lower reaches of the catchments, primarily within the tidal zone. However, only 9.6 % (107) of floodgates were located on Class 1 and 2 systems, with the remainder of the structures located on drains or modified waterway channels that displayed marginal fish habitat opportunities.

Fish passage remediation

Demonstration sites were developed by NSW DPI across the coastal catchments to illustrate best-practice techniques associated with the design, construction, and remediation of fish passage barriers. Selection of demonstration sites was based upon results from the fish passage audit and negotiations with relevant stakeholders. Funding for fish passage remediation was acquired from the NSW Environmental Trust, the Natural Heritage Trust, the NSW Catchment Management Authorities, and the NSW Recreational Fishing Freshwater Trust.

Road crossing remediation

Fish passage was remediated at 25 road crossing barriers, with stream connectivity being improved to 260 km of upstream habitat. NSW DPI's initial preferred remediation option for road crossing barriers, as for all structural barrier types, is the complete and permanent removal of the waterway crossing. Removal of obsolete crossings provides the best outcome for migratory fish species by reinstating natural water flows and sediment regimes, thereby improving aquatic and riparian health. In addition to the ecological benefits, removal of obsolete crossings is inexpensive (< $3,000) and rapid, with on-ground works generally completed in a single day. Considerations when removing instream barriers include investigating ancillary uses of the structure (e.g bed control), utilisation of sediment erosion control measures during the course of removal, and stabilisation of banks if road approaches are removed.

If a waterway crossing cannot be removed, NSW DPI's next preferred remediation option is the insertion of a bridge (Fig. 1A&B). Bridges, especially single-span structures, provide unimpeded water and sediment flow beneath the deck which allows for the free movement of migratory fish species. However, designs must ensure that the height and width of the bridge is matched to the associated waterway in order to avoid constriction of water flow, especially following minor river rises. Additionally, if the bridge is a multi-span structure, care must be given to the location of instream pylons to ensure that hydrological effects are minimised. Unlike obsolete removals, project costs and construction times tend to be highest with bridges; however, the use of prefabricated decks can reduce on-ground costs by 40 – 60 % due to shorter construction periods. A total of 6 bridges were constructed as part of this project, with costs ranging between $45,000 - $260,000 and timeframes varying from 1 – 15 weeks.

On smaller waterways, NSW DPI supports the insertion of multi-celled box culverts. The area beneath the crossing deck needs to be large enough to ensure that excessive increases in water velocity and turbulence do not occur with rising headwater levels (i.e. water height above the crossing). In order to prevent perching, the invert of the culvert cells should be set a minimum of 300 mm below the downstream water height (i.e. tailwater level) to ensure the pooling of water through the structure. A low flow channel can also be inserted into the middle culvert(s) to ensure adequate water depths (> 300 mm) are maintained through the structure during drier periods. Compared to bridges, box culverts initially appear less expensive. However unlike bridges, the construction of the base slab and wing-walls of box culverts requires considerable works instream. Contractors generally underestimate the difficulties and timeframes associated with the construction of coffer dams and diversion channels, thereby resulting in cost overruns that bring the final project costs in line with prefabricated bridges. Nine multi-celled box culverts were constructed during this project, with costs ranging between $45,000 - $360,000 and timeframes spanning from 1 – 24 weeks.

Weir remediation

The importance of fish passage at weirs and dams in NSW has been acknowledged since 1913 with the insertion of the first fishway at Audley Weir. Although 44 fishways were constructed in NSW by 1985, the pool-type designs were viewed as unsuitable for passing Australian native fish given that the internal specifications (e.g. slope, velocity, and turbulence) were based upon the swimming performance of Northern Hemisphere salmonids (Mallen-Cooper, 2000). Since 1985, three primary designs have been considered when constructing fishways at low-level weirs in NSW: vertical slot, denil, and rock-ramp fishways. Mallen-Cooper (2000) provides a comprehensive overview of design specifications for the three fishways relative to Australian fish passage.

Three fishways were constructed during the course of this project (vertical slot, full-width rock-ramp, and partial width reverse leg rock ramp) resulting in improved fish passage to over 90 km of upstream habitat (Fig. 1C&D). The low number of fishways constructed is indicative of the inherent considerations associated with this option (e.g. funding, design, construction and maintenance) that often result in protracted, multi-year timeframes. Regarding on-ground works, similar difficulties apply to fishways with regards to working instream as described for the construction of box culverts; however, additional consideration must be given to fishways to ensure that the chosen design suits not only the migrational patterns, swimming performance, and behavioural traits of target fish species, but also the hydrology of the system. For fishways to be effective, as defined by the passage of 95 % of fish species and size classes over 95 % of flows, a holistic understanding is required of fish ecology, hydrology, and geomorphology at each site. For the three projects listed above, fishway biologists and engineers were consulted to produce site-specific designs. Although site and design dependent, coastal fishways generally cost $150,000 for the first metre rise, then $100,000 for each subsequent metre. An additional consideration of fishways is the continued maintenance of the structure following construction to ensure that the prescribed hydrology is maintained, especially with regards to debris accumulation.

For obsolete and decommissioned weirs and dams, NSW DPI’s preferred remediation option is removal. Compared to the construction of fishways, removal of obsolete crossings is substantially less expensive (generally < $20,000). However, although on-ground works can generally be completed in a few days to a few weeks, considerations related to the ecological and social impacts of weir removal often result in multi-year project lengths. Since 1985, five weirs (Norco Weir, Branch Crossing, Bangalow Creek Weir, Bomaderry Weir, Muswellbrook Weir) have actively managed for removal in NSW coastal waterways.

A) B)

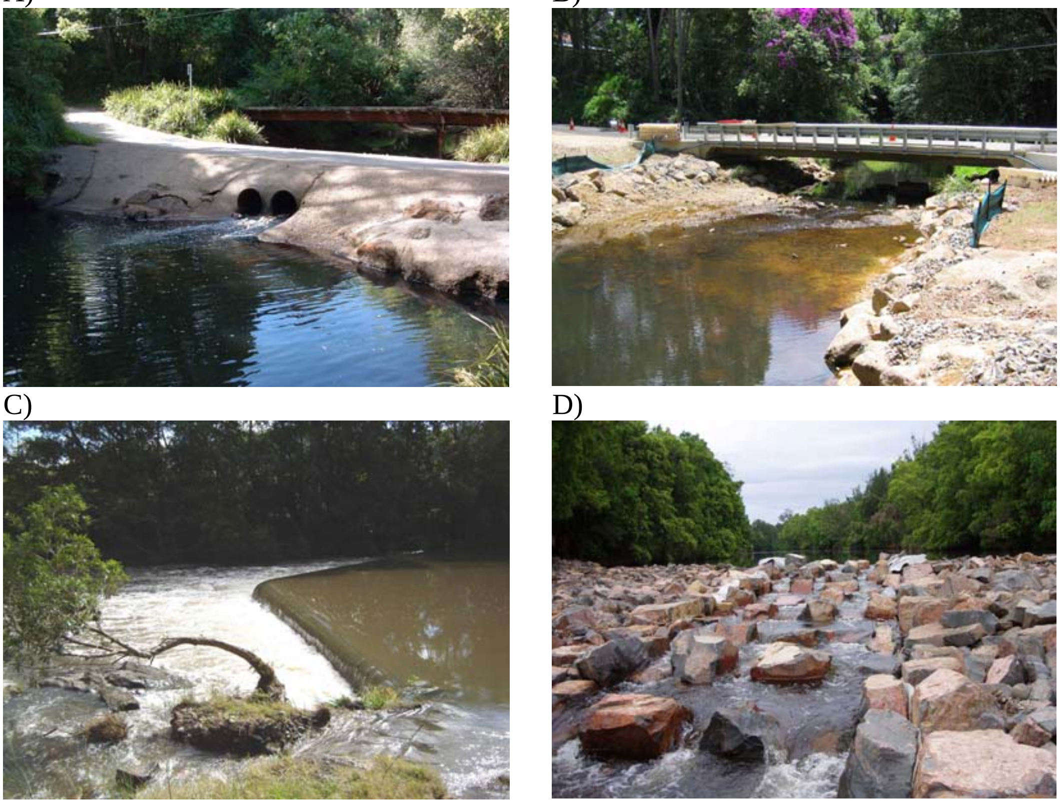

Figure 1. Remediation of fish passage at a tidal road crossing on the Brunswick River involved the replacement of a two-celled pipe causeway (A) with a prefabricated Doolan Deck bridge (B). Excessive headloss at Stroud Weir on the Karuah River (C) was overcome by the insertion of a full-width rock ramp with a central low-flow channel (D).

Floodgate remediation

Improved floodgate management has occurred at 57 sites during the course of this project, improving stream connectivity to over 600 km of upstream habitat. Floodgate remediation involved either a change to the management strategy of an existing winch or sluice gate, or the retrofitting of a hinged-flap gate with a fish-friendly design (i.e. winch, sluice, or auto-tidal gate). Site-specific project timeframes ranged from a few weeks to several years depending upon landholder support. Considerable attention is required to investigate the risks associated with reinstating tidal intrusion into drains including increased drain salinity levels, saline water overtopping of adjacent agricultural land, and lateral salt seepage into the surrounding groundwater.

However, benefits associated with active floodgate management include enhanced fish passage, improved water quality and sediment chemistry (e.g. dissolved oxygen, pH), and reduced drain weed management (Johnston *et al.*, 2003). Management plans were developed for each floodgate remediation site detailing the specific roles and responsibilities of relevant stakeholders. Where on-ground works were required, construction timeframes were relatively short (< 1 week), especially when retrofitting tidal or actively managed gates onto existing infrastructure. Although site and design specific, costs associated with floodgate remediation generally ranges from $10,000 - $15,000.

Conclusion

The construction of numerous instream structures has severely disrupted stream connectivity and fish passage within NSW and across Australia. Completion of the NSW DPI coastal fish passage audit provides an extensive overview of the scale of the problem facing stream managers, while also providing clear remediation priorities for weirs, road crossings, and floodgates. However, given the sheer number of fish passage barriers across the state, meaningful and measurable improvements to migratory fish populations will only result with a sustained level of investment to address relic barriers in the near future. It is equally important to ensure that existing acts (e.g. NSW Fisheries Management Act 1994) and policies (e.g. NSW State Weirs Policy) are enforced to make certain that new barriers are not created. NSW DPI, under sections 218-220 of the Fisheries Management Act (1994), has the responsibility to ensure that the construction of any new waterway structure, or the modification of an existing crossing, does not deleteriously impact upon resident fish populations. Finally, directed research is required to determine whether meaningful positive changes are occurring in fish populations and community structures as a result of barrier remediation. Research into the benefits of fish passage remediation has generally concentrated on fishways inserted on weirs located on western flowing systems. Where monitoring has occurred along coastal systems, results have been indifferent regarding the benefit of reinstating fish passage. However, this result is attributed to location of study sites high in the catchment, where multiple barriers were present downstream. BACI monitoring should be a required prerequisite of future fish passage remediation projects to identify realised benefits to our native fish, with barrier sites located low in the catchments being targeted.

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